BURN WOUND

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Wound care is the central theme of burn patient management after successful resuscitation. Burn wound care has been revolutionized during the past four decades. The development of effective topical chemotherapy, the timely surgical removal of burned tissue, and the availability of clinically effective biologic dressings and skin substitutes have reduced the incidence of invasive burn wound infection, altered the character of the burn wound infections that do occur, effected earlier closure of the burn wound, and contributed to the improved survival of burn patients.

BURN WOUND DEPTH

The depth of the burn wound is the principal determinant of wound management, but the extent of the burn may dictate treatment modification in terms of priority of excision, the timing of excision as influenced by complications and comorbid conditions, and the need for biologic dressings and skin substitutes. Burn depth is defined by the thickness of dermis that has been damaged by thermal energy, i.e., the presence or absence of viable skin appendages from which spontaneous healing can occur. Third-degree or full-thickness burns, in which the entirety of the dermis has been destroyed and there are no surviving skin appendages, require debridement to remove the nonviable tissue and skin grafting to achieve definitive closure. Partial-thickness burns, in which there is a variable thickness of unburned dermis, are further subdivided into superficial and deep

partial-thickness injuries. Superficial partial-thickness injuries, if protected from infection, characteristically heal in 7 to 10 days with a functional and cosmetic result that cannot be improved upon by excision and grafting. Deep partial-thickness burns, even if protected from infection by the application of effective topical chemotherapeutic agents, require more than 10 to 21 days to heal, and when healed manifest hypertrophic scar formation, with the amount of scar proportional to the time required for healing.

Historically, a differentiation was made between partial-thickness burns that would heal within 21 days and those that would require more than 21 days, since the healing of the latter could be improved by excision and grafting. Assessment of the need to excise and graft deep partial-thickness burns was characteristically made by serial examination in the first 2 weeks after the burn, with excision planned and carried out as soon as it was evident that the wound would not heal spontaneously within the 3-week period. In recent years, improvements in wound care, including the use of tangential excision and a greater surety of graft take, have reduced the accepted time limit for spontaneous healing. It is now commonly recommended that if a burn wound will not heal in 10 to 14 days, excision should be undertaken to improve functional and cosmetic results, decrease in-hospital time, and reduce the cost of burn care.

Although some reports have suggested that blood loss is reduced and hospital stay decreased by excision within the first 24 to 48 hours of burn injury, the techniques used to measure blood loss in such studies have been of uncertain reliability. Moreover, ablation of the compensatory responses to early postburn hypovolemia by general anesthesia, with its associated risk of cardiac arrest, in the absence of documented beneficial effect provides little support for such early excision.

INITIAL TREATMENT

Initial treatment of all burn wounds consists of debridement of loose, nonviable tissue and bullae greater than 2 cm in diameter, followed by gentle cleansing with a surgical detergent disinfectant such as chlorhexidine, and shaving of the body hair from the burn wound and a generous margin of unburned skin. After the initial cleansing, topical chemotherapy is begun by the application of mafenide acetate (Sulfamylon) burn cream, silver sulfadiazine (Silvadene) burn cream, or 0.5 percent silver nitrate soaks. All three topical agents are of equal effectiveness when treatment is begun immediately after the burn injury. If, for some reason, topical therapy must be delayed and a significant microbial population proliferates within the eschar, Sulfamylon burn cream, from which the antimicrobial agent, mafenide acetate, readily diffuses into the burned tissue, is the preferred agent. I use alternate application of Sulfamylon and Silvadene burn creams, the former applied after the daily morning chlorhexidine cleansing of the burn wounds and the latter applied 12 hours later. Such alternate applications appear to minimize the side effects of each agent and realize the advantages of both.

BURN WOUND EXCISION

After resuscitation, partial-thickness burns that are deemed to require excision can be excised by the tangential excision technique, in which successive thin layers of nonviable tissue are removed with any of a variety of dermatomes or guarded skin knives. A Humby knife can be used to expedite excision of broad planar areas in which the dermis is thick and the burn depth is at least deep dermal (Fig. 1*A*). Weck dermatomes and either air-driven or electric dermatomes can be used on body parts that have a lesser radius of curvature, and rotary dermabraders can be used for tangential excision of burns in the web spaces of the hands and feet or other hard-to-reach areas (Fig. 1*B*). The blood loss associated with tangential excision can be prodigious (more than 9 percent of circulating blood volume per percentage of body surface excised has been reported). Techniques used to minimize blood loss have included mechanical avulsion of the eschar to narrow the vascular lumina and thereby reduce blood flow, use of the carbon dioxide laser or the heated scalpel, use of tourniquets when excising burns from a limb, and the infiltration of a solution of ornithine vasopressin in areas where a tourniquet cannot be used.

The end point of tangential excision is the presence of uniformly dense capillary bleeding from the entirety of the burn wound bed. Hemostasis is achieved by spray application of a thrombin solution, after which Telfa sheeting (which minimizes rebleeding when removed) is placed on the wound surface, followed by application of sponges wet with a warm, dilute solution of epinephrine, which are held in place by a pressure dressing. When that dressing is removed, discrete bleeding vessels are controlled by electrocautery or, if of sufficient size, suture ligature.

When hemostasis has been achieved, the wounds are covered with sheets of split-thickness autograft skin, meshed split-thickness autograft skin, or a biologic dressing, depending on the availability of donor sites. Typically, the skin grafts are fixed in position with skin staples, but sutures may be used for the same purpose. The grafts are protected by an occlusive dressing consisting of a single layer of fine mesh gauze covered with gauze sponges, which are held in place with semielastic Kerlix dressings and elastic tubular mesh gauze. If the grafts extend across joints, the limb or neck can be immobilized as necessary by intraoperative application of a splint or positioning device fabricated of heat-malleable material. If mesh grafts are used, desiccation of the wound bed exposed in the interstices of the graft is prevented and bacterial proliferation in those areas controlled by the use of dressings soaked with a 5 percent solution of mafenide acetate, which are remoistened every 2 to 4 hours.

Excision of full-thickness burns can be done either

Figure 1 *A,* A guarded knife, such as the Humby knife shown here, can be used to remove deeply burned, nonviable tissue from a flat surface such as the dorsum of the hand. *B,* A rotary dermabrader is used to remove the nonviable tissue from irregular surfaces such as that over the metacarpal joints and web spaces on the dorsum of the same hand.

by the tangential technique or, if the burn obviously involves the subcutaneous fat, by scalpel excision at the level of the investing fascia (Fig. 2). This form of excision is associated with a lesser blood loss and can be done more expeditiously, but produces more cosmetic deformity, particularly at the margin, where there may be a sizeable "step-off" between the level of unburned skin and the investing fascia. It is more difficult to identify with assurance viable subcutaneous fat than it is to identify viable dermis. Consequently, when the burn extends into subcutaneous fat, many surgeons prefer to carry out the excision at the level of the investing fascia. Wounds in which the base of the wound is the investing fascia are closed in the same manner as are those wounds in which the base of the wound is viable dermis. To reduce the step-off from the skin surface at the edge of the wound to the surface of the fascia, some authors have recommended undermining the skin at the margin of the wound and excising a wedge of subcutaneous tissue to permit suture apposition of the skin edge and the investing fascia. The risk of infection of the undermined skin and the spontaneous remodeling that reduces the step-off have limited the use of such undermining.

Overall, 20.6 percent of wound manipulations induce bacteremia, but its incidence is proportional to the intensity of the manipulation and the extent of the burn. That association justifies perioperative administration of antibiotics active against both gram-positive and gram-negative organisms. In adult patients, 1 g vancomycin is administered intravenously during the hour before operation, 12 hours later, and 12 hours after that. In children weighing less than 50 kg, the vancomycin dosage is reduced to 10 mg per kilogram. Amikacin, 5 mg per kilogram, is infused immediately before surgery, 8 hours later, and 8 hours after that. In patients with impaired renal function or those considered to be at risk for renal failure, 1 g ceftazidime given in the same dosage schedule can be substituted for the aminoglycoside. Antibiotic prophylaxis can be abbreviated to the initial 1 g dose of vancomycin if the wounds are clean and involve less than 10 percent of the body surface.

Although lengthy one-stage excisions of the burns of patients with extensive injuries (more than 50 percent of total body surface) have been carried out, burn wound excision procedures are usually limited to 20 percent of the body surface or 2 hours' operating time, to avoid excessive blood transfusion needs and ensure that the associated physiologic stress can be tolerated. In patients with massive burns, excision procedures are commonly staged. If the clinical condition permits, the patient can be returned to the operating room every 2 or 3 days for a similar excision procedure until all burn wounds have been excised.

In patients with burns of more than 50 percent of body surface, the burns on broad relatively immobile body areas, such as the anterior trunk and anterior thighs, have priority for excision because of the rapidity with which excision can be carried out and the greater likelihood of a good take of the initial harvest of autograft skin. Burns of the back and buttocks are usually the last to be excised. The thickness of the dermis of the skin overlying those areas permits spontaneous healing of burns that in other areas would require grafting. Moreover, spontaneous patient movement, and the forces applied when moving the patient during nursing care procedures, increase the risk of shear-related loss of grafts applied to the back and buttocks. In patients with burns of lesser extent, functional areas, i.e., arms, hands, legs, feet, and the neck, have priority for excision in order to optimize functional recovery. As in

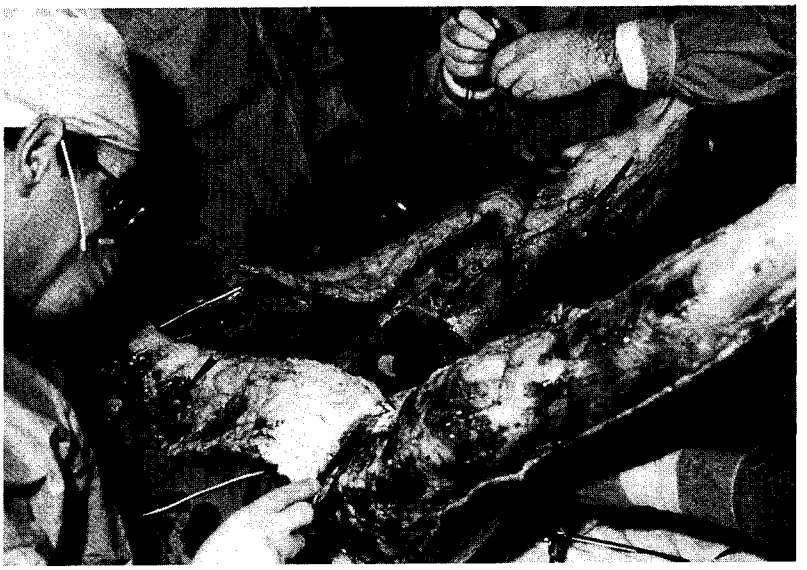

Figure 2 Scalpel excision at the level of the investing fascia is used to excise burns in which the subcutaneous tissue is involved, as shown by the hemorrhagic discoloration *(arrow)* of the undersurface of the tissue that has been excised and reflected from the anterior surface of the right leg.

the back, the thickness of the dermis on the face permits spontaneous healing of many burns that initially appear to involve the full thickness of the skin. Consequently, conventional therapy has consisted of expectant treatment of facial burns, with grafting reserved for those areas that have not healed within 3 to 4 weeks. More recently, early excision of deep facial burns has been reported to improve both cosmetic and functional results.

The dressings applied to split-thickness skin grafts are examined daily, and in the absence of bleeding, pain, foul-smelling discharge, and systemic signs of infection, are left in place for 5 days, at which time the dressings are removed and the grafts inspected. Seromas and hematomas can be evacuated and the overlying graft collapsed onto the underlying wound bed. The grafts are re-dressed and changed on a daily or every-other-day basis until the tenth postgrafting day, at which time the grafted part can be gently mobilized and ambulation begun, with the grafts protected by occlusive dressings as necessary. In the case of mesh grafts, occlusive dressings are continued until the interstices are closed by spread of epithelium from the mesh reticulum. The time required for such epithelialization is proportional to the expansion ratio. That time is so prolonged in grafts that are expanded at a 6:1 or 9:1 ratio that expansion beyond 4:1 is seldom utilized, except in patients with truly massive burns that involve 60 percent or more of the body surface.

The skin graft donor sites are covered with fine mesh gauze over which laparotomy pads soaked in warm saline are applied and left in place until the patient is ready to leave the OR. The donor sites are thereafter exposed to heat lamps until they dry completely. The fine mesh gauze is trimmed as it separates from the healing donor site over the next 10 to 12 days. The dried fine mesh gauze can cause discomfort when the donor site is subject to motion or stretching. Consequently, a donor site dressing such as a thin polyurethane film, permeable to oxygen and water vapor, which maintains a moist interface with the donor site surface, is less painful and associated with faster healing than fine mesh gauze.

RESULTS

A review of the treatment and outcome of 171 patients with burns of 30 percent or more of total body surface treated during a recent 2½-year period helps place burn wound excision in clinical perspective. Of these patients, 118 (69 percent) survived and 53 (31 percent) died. The average age, 26.2 years, and the average extent of burn, 46.2 percent of body surface, in the survivors were much less than in the patients who died, in whom they were 38.7 years and 63.6 percent of total body surface. The average extent of full-thickness burn, 20.1 percent of total body surface, in the survivors was less than half that in the nonsurvivors, 46.6 percent of total body surface. In addition to those differences, inhalation injury (a powerful comorbid factor) was present in only 32 (27 percent) of the survivors, but 29 (55 percent) of the nonsurvivors. Excision was carried out in 114 (99.2 percent) of the 118 survivors, but was possible in only 31 (58 percent) of the nonsurvivors. In the nonsurviving patients, the average time of first excision was 6.8 days postburn, with a range of 4 to 12 days. In the survivors, the time of first excision ranged from 2 to 25 days postburn. The average time to first excision in that group of patients was 9.7 days postburn, which represents the effect of what appears to be a bimodal distribution of time to first excision. In the patients with unequivocal full-thickness or readily diagnosed deep dermal burns, excision was conducted during the first postburn week, but in patients in whom excision was delayed, in anticipation of healing that did not occur in a timely fashion, the time of first excision was the latter part of the second or even during the third postburn week.

The greater number of patients who did not undergo excision in the group of nonsurviving patients cannot be used to infer a beneficial effect of excision in light of the greater age, extent of burn, and frequency of inhalation injury and other comorbid factors in the unexcised patients who died. The conditions that preclude or cause delay of excision in patients with extensive burns are listed in Table 1. If minute ventilation exceeds the transport ventilator capacity, safe transport to the OR is not possible. Those conditions that only delay excision, such as cellulitis, electrolyte disturbances, pulmonary edema, and hypovolemia, may be of relatively brief duration and typically respond rapidly to treatment. Conversely, myocardial infarction, septic shock, pulmonary embolus, and disseminated intravascular coagulation (DIC) typically require more prolonged treatment, which may cause protracted delay in excision or even preclude such treatment. Of the 22 nonsurviving patients who did not undergo excision, 15 were excluded because of pulmonary insufficiency, five because of hemodynamic insufficiency, and two because of sepsis-induced DIC.

INVASIVE BURN WOUND INFECTION

Although effective topical chemotherapy has significantly decreased the occurrence of invasive burn wound infection, that life-threatening complication may occur if excision of the burn wound is inordinately delayed, or if definitive closure of the burn wound is delayed after excision because of paucity of donor sites or because of delayed closure of widely expanded mesh grafts, i.e., 6:1 or 9:1 expansion ratios. The high mortality associated with invasive burn wound infection necessitates assiduous monitoring to identify the disease at a stage where therapeutic intervention can control the infection and salvage the patient. The local signs of burn wound infection include those listed in Table 2. The most frequent sign is focal or multifocal dark red, brown, black, or violaceous discoloration of the wound, but similar changes can occur as a result of hemorrhage into the wound caused by even minor local trauma. The most reliable local sign is the sudden conversion of an area of partial-thickness injury to full-thickness skin necrosis. This change can be of impressive extent in the case of the rapid centrifugal spread of ischemic necrosis characteristic of phycomycotic infection. As noted, there are other local signs characteristic of specific bacterial, fungal, and viral infections.

Identification of any of these signs necessitates additional diagnostic maneuvers to assess the microbial status of the burn wound. The association of invasive burn wound infection with a high tissue density of bacteria has led some authors to place unwarranted reliance on quantitative bacteriology as a means of diagnosing burn wound infection. Quantitative surface cultures can be falsely positive if pooled secretions are cultured or, conversely, falsely negative if a desiccated wound surface is cultured or residual topical agent is included in the culture. Quantitative cultures, even of biopsy specimens, are helpful only in a negative sense: i.e., low counts are reliably associated with absence of infection, but histologic evidence of infection is absent in more than 50 percent of patients in whom quantitative cultures are reported as positive. Histologic examination of a biopsy specimen is the only reliable means of differentiating the colonization of nonviable tissue from the invasion of viable tissue.

The area of the burn wound showing the most advanced local signs of infection should be the site of the biopsy (Fig. 3). This area is cleansed and a 500 mg lenticular biopsy specimen, which includes both eschar and underlying subcutaneous tissue, is harvested by scalpel excision. One-half of the specimen is processed by frozen and subsequent rapid section technique for histologic examination, and the other half is processed for culture and sensitivity testing. Identification of

Table 1 Conditions That Preclude or Delay Excision

Acute electrolyte disturbance
Uncontrolled cellulitis
Acute pulmonary embolus
Disseminated intravascular coagulation
Minute ventilation exceeding transport ventilator capacity
Inadequate tissue perfusion
Hypovolemia
Septic shock
Myocardial infarction
Brain death

Table 2 Clinical Signs of Invasive Burn Wound Infection

Focal, multifocal, or generalized dark red, brown, or black discoloration of eschar
Conversion of partial-thickness injury to full-thickness necrosis
Hemorrhagic discoloration of subeschar tissue
Edema and/or violaceous discoloration of unburned skin at wound margin
Green pigment visible in subcutaneous fat*
Erythematous necrotic lesions (ecthyma gangrenosum) in unburned skin*
Accelerated eschar slough†
Rapid centrifugal expansion of subcutaneous edema with central necrosis†
Vesicular lesions in healing or healed partial-thickness burns‡
Crusted serrated margins of partial-thickness burns of face‡

*Characteristic of *Pseudomonas* infection.
†Characteristic of fungal infection.
‡Characteristic of herpes simplex infection.

microorganisms in viable tissue confirms the diagnosis of invasive burn wound infection. Table 3 lists the other histologic findings indicative of invasive burn wound infection. Identification of these findings in the absence of microorganisms in viable tissue should prompt examination of additional histologic sections or repeat biopsy of another area of the wound suspected of harboring infection.

Confirmation of invasive burn wound infection necessitates immediate change in both wound and general care. Systemic support measures should be employed to ensure adequate ventilation and tissue perfusion. Systemic antibiotic therapy should be initiated by administration of those agents active against the likely causative organism, as assessed by the burn center's microbial surveillance system. This therapy is subsequently modified if necessary on the basis of the biopsy specimen culture and sensitivity testing results. A broad-spectrum penicillin (one-half the daily dose in 250 to 1,000 ml of normal saline) should be subcutaneously injected into the infected areas, with such injection repeated 6 to 12 hours later immediately before surgical excision of all the infected tissue. The wound is dressed open and the patient is returned to the OR in 24 to 48 hours, at which time further excision is carried out if necessary; alternatively, if the infection has been controlled by the initial excision, the excised wound bed is covered with cutaneous autografts or a biologic dressing.

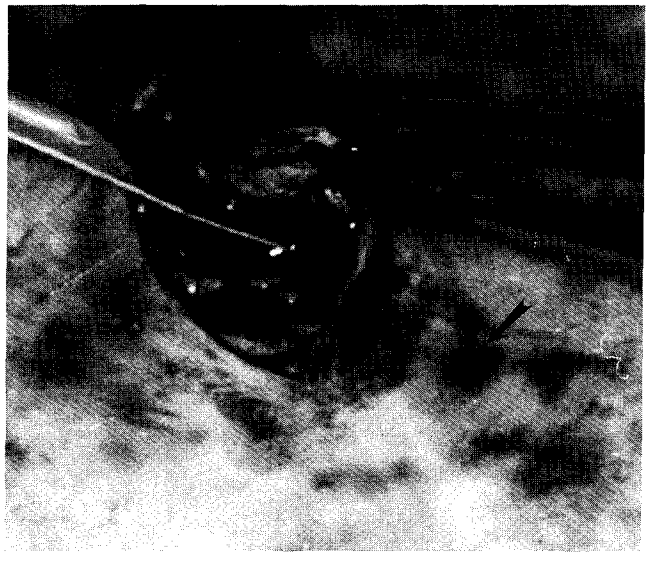

Figure 3 The appearance of focal areas of dark discoloration, as evident on the burns of this thigh *(arrows),* mandates a wound biopsy. A scalpel is used to obtain the biopsy specimen, which must include unburned subcutaneous tissue. The tissue sample is processed for both culture and histologic examination.

Table 3 Histologic Signs of Burn Wound Infection

Microorganisms present in unburned tissue
Intracellular viral inclusions
Heightened inflammatory reaction in underlying unburned tissue
Hemorrhage present in viable subeschar tissue
Small vessel thrombosis and ischemic necrosis in unburned tissue
Dense microbial growth along hair follicles and sweat glands*
Intense microbial proliferation in subeschar space*

*Characteristic of deep colonization.

BIOLOGIC DRESSINGS

If available donor sites are of such limited extent that an excised burn cannot be autografted, a biologic dressing must be employed (Table 4). Viable cutaneous allografts are the gold standard of biologic dressings, but their usefulness is compromised by processing and storage requirements, limited shelf life, and the possibility of viral and other disease transmission. Alternative biologic dressings include cutaneous xenografts (typically porcine) and amniotic membranes. Neither of these dressings is vascularized by the host, as are cutaneous allografts, and neither exerts as effective microbial control of submembrane microorganisms. Moreover, amniotic membranes can transmit the same diseases as can cutaneous allograft.

SKIN SUBSTITUTES

The limitations of biologic dressings have led to the development of a variety of skin substitutes, which must be of bilaminate construction, with an epidermal analogue serving a barrier function and a dermal analogue that permits biologic union to occur between the membrane and the wound bed. There are two commonly used skin substitutes, both of which have a Silastic epidermal analogue and a collagen-based dermal analogue. When the wound to which it is adherent is ready for grafting, Biobrane is removed in its entirety, after which the autograft skin is applied (Fig. 4). The other membrane, Integra, which has been clinically evaluated,

Table 4 Biologic Dressings and Skin Substitutes

Naturally occurring tissues
Cutaneous allografts
Cutaneous xenografts
Amniotic membranes
Collagen-based composite skin substitutes
Biobrane
Integra
Culture-derived tissue
Cultured autologous keratinocytes
Chimeric cultured keratinocytes (5% or more autologous and 95% or less allogeneic cells)
Fibroblast-seeded dermal analogues
Collagen fibril glycosaminoglycan–enriched membrane
Polyglycolic or polyglactin acid mesh
Collagen sponge
Processed dermis used as bed for cultured keratinocytes
Frozen allograft skin debrided of epidermis
Allodermis processed to delete antigenic material

Figure 4 The collagen-based bilaminate skin substitute (Biobrane) being removed from this wound was applied at the time of burn wound excision. Note the translucent character of the Biobrane adherent over the upper back, which permits ready identification of submembrane suppuration. Removal of the membrane reveals a readily graftable bed of granulation tissue that had effected biologic union with the dermal analogue of the membrane.

consists of a fibrillar collagen mat enriched with 6-chondroitin sulfate as the dermal analogue. When the ingrowth of host tissue has adequately vascularized that layer, the Silastic epidermal analogue can be removed and an ultra-thin cutaneous autograft applied directly to the vascularized dermal analogue, which then serves as a template for dermal reconstitution. The collagen-based skin substitutes do not perform well on heavily colonized wounds and are most effective as skin substitutes when applied to freshly excised burn wounds. In a multi-institutional study in which Integra was compared with a variety of biologic dressings, the investigators reported that Integra was associated with less hypertrophic scarring, more rapid donor site healing, and greater patient preference. At present, Integra is not approved for clinical use.

CULTURED EPIDERMAL AUTOGRAFTS

The limitations of the skin substitutes have generated considerable interest in the development of culture-derived epidermal sheets. These, too, appear to be of limited clinical effectiveness. In 19 patients treated at the US Army Burn Center with cultured epidermal autografts, the average take of such tissue at the first dressing change, 10 days after application, was 47.8 percent, but that had decreased to 30.6 percent at the conclusion of initial evaluation 21 to 28 days after application. The take of such cultured epidermal autografts was compromised by the presence of gram-negative organisms and fungi on the burn wound, by application to a posteriorly situated wound, by application to an area subject to shear force, and by application to a wound bed made up of granulation tissue. Of greatest concern was the observation that the take of cultured epidermal autografts was inversely proportional to the extent of the burn. The average extent of burn definitively closed by the use of cultured epidermal autografts in the 19 study patients ranged from 0 to 18.4 percent, with a mean of only 2.8 percent of total body surface area.

The limited usefulness of currently available cultured epidermal autografts has served as a stimulus for the current development of a culture-derived dermis (e.g., the collagen mat dermal analogue of Integra seeded with neonatal fibroblasts) and the production of a culture-derived composite tissue consisting of a dermal analogue with adherent cultured epidermal cells. Alternatively, adherent frozen cutaneous allografts from which the epidermis has been surgically removed and a processed "nonantigenic" allodermis are being evaluated as templates for neodermis formation that serve as substrates for application of cultured epidermal autografts.

The current techniques of burn wound care developed over the past four decades reduce the magnitude and duration of burn-related physiologic stress and organ dysfunction, as well as the occurrence of wound sepsis and other complications. Effective topical chemotherapy maintains a low density of microorganisms in the wound until the burn tissue can be surgically excised. The use of meshed autografts or, alternatively, a biologic dressing or a skin substitute followed by autograft application when donor sites can be reharvested or, more recently, the application of cultured epidermal autografts permit timely closure of even massive burn wounds that have been excised. These improvements in burn care have significantly reduced the incidence of invasive burn wound infection, effected earlier closure of the burn wound, improved both functional and cosmetic results, and reduced the mortality associated with burn injury.

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